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SPH-4 HELMET DAMAGE AND HEAD INJURY CORRELATION

By

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Biomedical Tolerance

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20. ABSTRACT:

Human tolerance to head impact was assessed by correlating the force levels required to duplicate damage seen in 12 SPH-4 aviator helmets retrieved from US Army helicopter crashes with resulting head injury. Head injury occurred at peak acceleration levels far below 400 G, which is the value currently used by the US Army as the pass-fail criterion in evaluating the impact attenuation performance of prospective aircrew helmets. Concussive head injuries occurred below Severity Index values of 1500 and below Head Injury Criterion values of 1000. These are considered concussive threshold values by the National Operating Committee on Standards for Athletic Equipment and by the Department of Transportation, respectively.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLE

INTRODUCTION

The ANSI Z90.1-1971 (1971) method, called out in Military Specification MIL-H-43925 (DA 1975) and currently used by the US Army for evaluating the impact attenuation performance of prospective aircrew helmets, relies primarily on peak G as a pass-fail criterion. A candidate helmet is attached to an instrumented metal headform and dropped from a height yielding 95 joules of input energy onto a 4.8-cm radius steel hemisphere. Helmets which prevent the peak acceleration experienced by the headform in such impacts from exceeding 400 G meet the Army standard for impact performance and qualify for use by Army aircrewmen. However, based on the incidence of head injury in survivable Army aircraft accidents, it can be questioned whether or not the current Army standard adequately reflects human tolerance limits to head impact. This paper will attempt to answer that question.

To date, efforts to define human tolerance to head impact have been confined, necessarily, to studies involving animals or human cadavers. However, in 1972 the Army's establishment of the Life Support Equipment Retrieval Program provided a unique opportunity to research directly human tolerance limits to head impact. Since 1972, helmets involved in Army aircraft accidents worldwide have been retrieved for laboratory analysis. If it is assumed that the damage seen in a retrieved helmet accurately reflects the force experienced by the wearer's head in the crash situation, then those force levels can be identified by duplicating that degree of damage on a similar helmet under controlled conditions. By comparing force levels to resulting head injury, human tolerance limits to head impact can be defined.

MATERIALS AND METHODS

A total of 12 SPH-4 helmets was selected for impact damage simulation from those flight helmets analyzed in the retrieval program to date. Two of the helmets had received two impacts each; however, neither of the helmet wearers received head injuries from the impacts, so each impact was considered independent of the other for a total of 14 impact cases.

These 12 simulation helmets were selected because the impact was not a glancing blow; thus, all head injury is assumed to have resulted primarily from translational acceleration. The centers of the impact locations on both the helmet and the head for the 14 cases selected for impact damage duplication is summarized in Figure 1. The impact locations shown on the helmet shell are precise; those on the head are approximate since some relative movement is possible between the helmet and head during the impact.

FIGURE 1. Of the 14 cases studied, 6 were frontal impacts, 4 were crown, 2 were side, and 2 were located at the back of the head. The center of each impact shown on the helmet is precise; those of the head are only approximate since some movement between helmet and head is possible during impact.

Spare helmet components were assembled to produce several duplicates for each of the 14 cases. Each duplicate helmet was prepared so that its shell thickness, liner thickness, and adjustment of suspension straps matched that of the retrieved helmet as closely as possible. To reproduce the damage of a given retrieved helmet, duplicates for that helmet were attached to a modified version of the humanoid headform specified by the National Operating Committee on Standards for Athletic Equipment (NOCSAE) for evaluating football helmets (Hodgson 1975). As shown in Figure 2, the head-neck connection of this headform was modified to increase its adjustability and permit mounting on the standard carriage assembly specified by the ANSI Z90.1-1971 method. A tri-axial accelerometer (Endevco Model 2267C-750)* was positioned at the head form's center of mass. Its signal was amplified by a signal conditioner (Endevco Series 4470)* and fed to a three-channel vector analyzer. The vector resultant

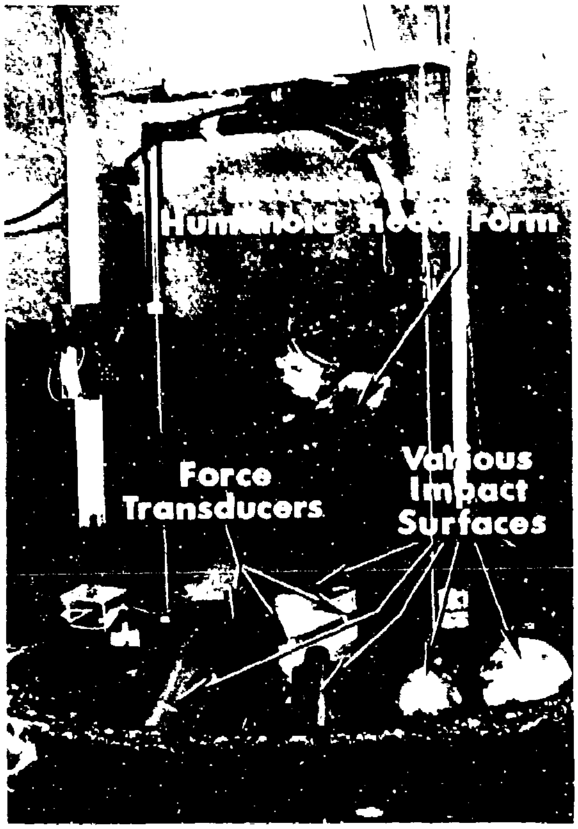

FIGURE 2. Retrieved helmet damage was duplicated by attaching a test helmet to this instrumented humanoid head form and impacting it onto a surface of appropriate shape. Peak transmitted force was measured using the resultant of three force transducers located beneath the impact surface. Drop height was varied until the best damage duplication was achieved.

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* Enveco Model 2267X-750, Becton, Dickinson & Co., Rancho Viejo Rd San Juan Capistrano, CA 92675.

of the three accelerometer signals was then transmitted to the hybrid computer, which computed the values of peak G, Severity Index (SI) as described by Gadd (1966), and Head Injury Criterion (HIC) as defined by Chou and Nyquist (1974). Total weight of the head form and carriage was 5 kg.

The helmeted head form was then dropped onto an impacting surface that had been selected to reproduce the type of damage seen on the retrieved helmet. Some helmets required a concave impact surface to duplicate the area of compression seen in the foam helmet liner. These concave impact surfaces were prepared by taking an impression of the helmet shell at the impact site using dental cement. These cement impressions were then used as impact surfaces. Three piezoelectric force transducers (Kistler type 9021)* were positioned beneath the impact surface as shown in Figure 2. The drop height was varied until the damage produced in the duplicate helmet matched that of the retrieved helmet.

Damage was assumed to have been duplicated when a) the amount of bending in the six suspension strap anchor clips was duplicated, as shown in Figure 3; b) the area and maximum deflection of the foam helmet liner was duplicated, as shown in Figure 4; and c) the degree of fracture

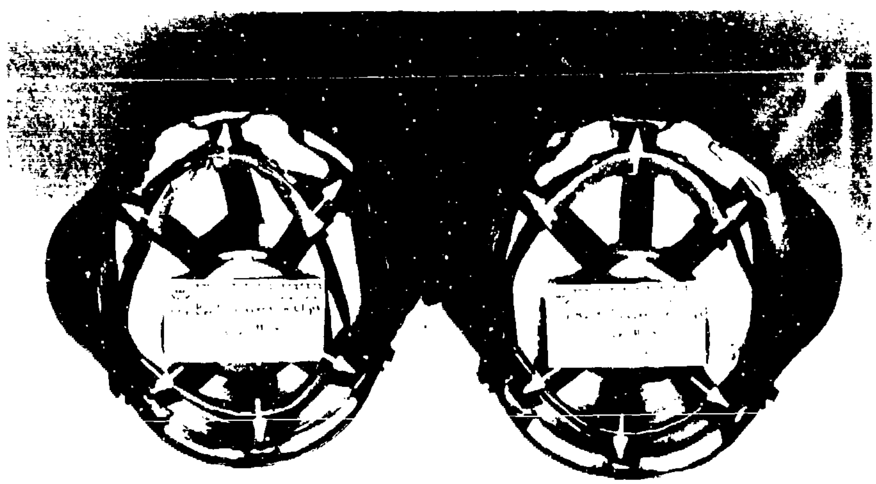

FIGURE 3. The amount of bending in the six suspension strap anchor clips was duplicated for each of the 14 cases.

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* KIAG Swiss, Kistler Instrumente AG, CH 8408, Winterthur, Switzerland.

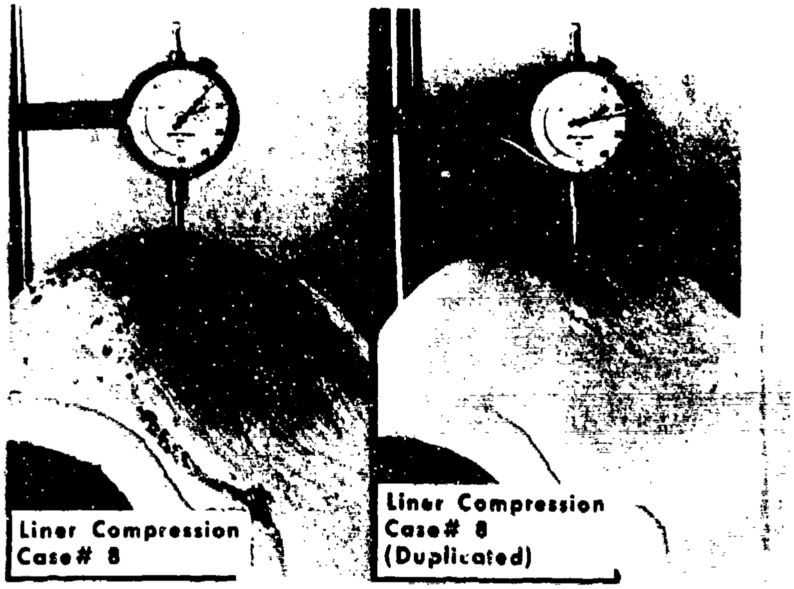


FIGURE 4. Helmet liner damage was duplicated by matching the area and maximum compression produced in the test helmet liner with that of the retrieved helmet liner. Maximum compression was duplicated to within a few thousandths of an inch.

in the fiberglass helmet shell, as shown in Figure 5, matched that of the retrieved helmet. Acceleration vs. time and force vs. time traces were recorded for each impact and are shown in Figure 6. A description of head injuries associated with any of the 14 cases was obtained by reviewing the official accident report supplied by the US Army Safety Center. All head injuries were assigned a severity value using the Abbreviated Injury Scale (AIS) (1976).

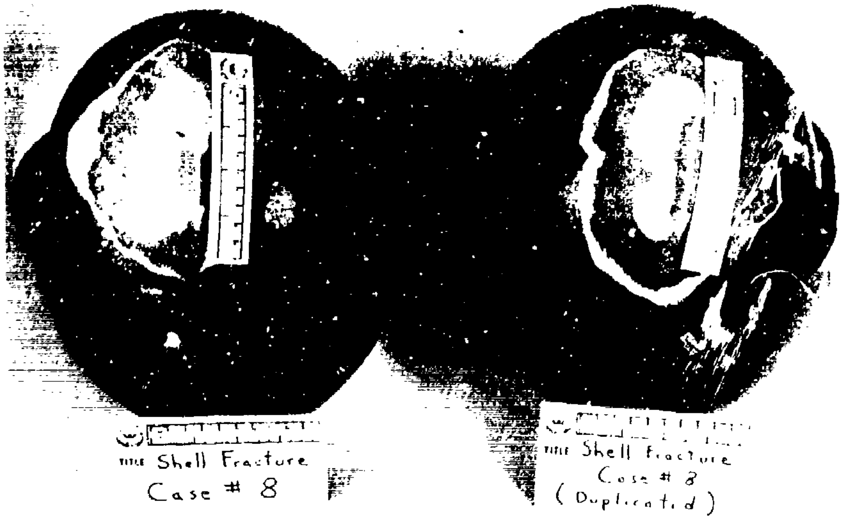
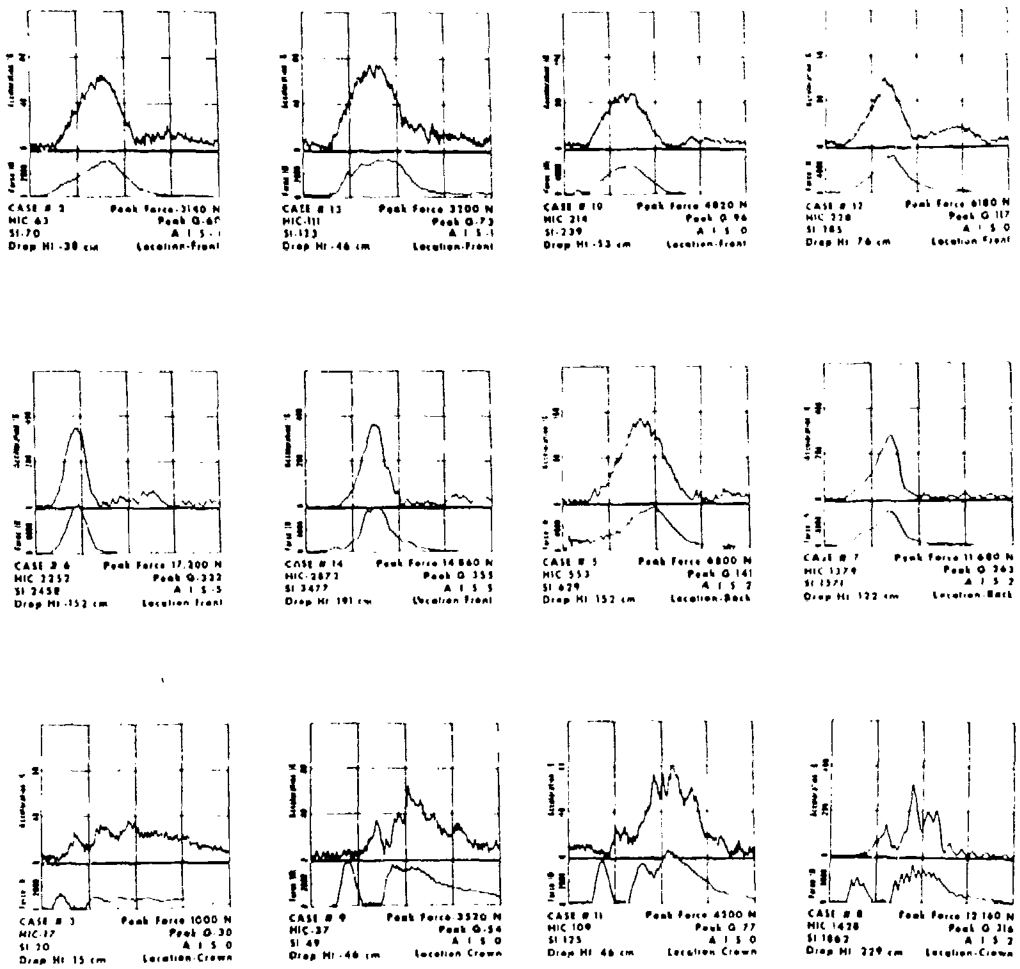


FIGURE 5. The degree of fracture in the fiberglass helmet shell was duplicated for those cases in which shell fracture occurred.



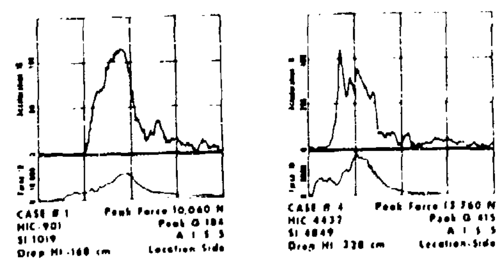


FIGURE 6. Acceleration vs. time and force vs. time traces for the 14 cases synchronized in time. Time axis divisions equal 4 ms. The initial pulse seen on the force traces of cases 3, 9, 11, and 8 represents the helmet's initial contact and rebound off the impact surface. This double pulse occurs only in crown impacts where helmet weight causes some separation between helmet and headform permitting the helmet to rebound initially independently of the headform.

RESULTS

A description of head injuries, of conditions required to duplicate helmet impact damage, and of the data recorded for each of the 14 cases is shown in Table 1. Only three of the 14 cases required an impact surface more severe than that of a flat surface to duplicate the helmet damage. In all eight cases involving head injury, the foam helmet liner was not compressed to the maximum extent possible. Only in case No. 5 did head injury result from the impact surface penetrating the helmet shell. All three cases in which fracture occurred involved forcing the head down against the spinal column resulting in either basilar skull fracture or fracture of the first cervical vertebra.

The peak acceleration judged to have been experienced in the 14 cases comprising this study, based on the best damage duplication, is shown in Figure 7. Head injury occurred well below the 400-G criterion currently used by the US Army in evaluating the impact performance of prospective aircrew helmets.

SI and HIC values were calculated for each of the 14 cases and are shown in Figure 8 and 9 respectively. Concussive head injuries occurred at SI values below 1500, which is the value currently used as the concussive threshold by NOCSAE in evaluating the impact performance of football helmets. Concussive head injuries also occurred at HIC values below 1000, which is the value currently adopted by the Department of Transportation (DOT) in Federal Motor Vehicle Safety Standard No. 208 (1972) for occupant crash protection tests as the limit of human tolerance for impact to the unprotected head.

DISCUSSION

The low incidence of penetrating types of head injuries among Army helicopter crash victims appears to be due primarily to a) an absence of sharp, rigid cockpit surfaces, and b) the effectiveness of the SPH-4 aviator helmet as a load-spreading device.

On the other hand, the energy-absorbing capability of the helmet appears inadequate based upon the high incidence of concussive types of head injuries observed. This deficiency can have disastrous effects, as seen in cases 4 and 6 where basilar skull fracture occurred as a result of the helmet transmitting, rather than absorbing, the impact force. Recent in-house studies (unpublished) have shown that the energy-absorbing ability of the helmet can be more than doubled by simply increasing the thickness and decreasing the density of the foam helmet liner.

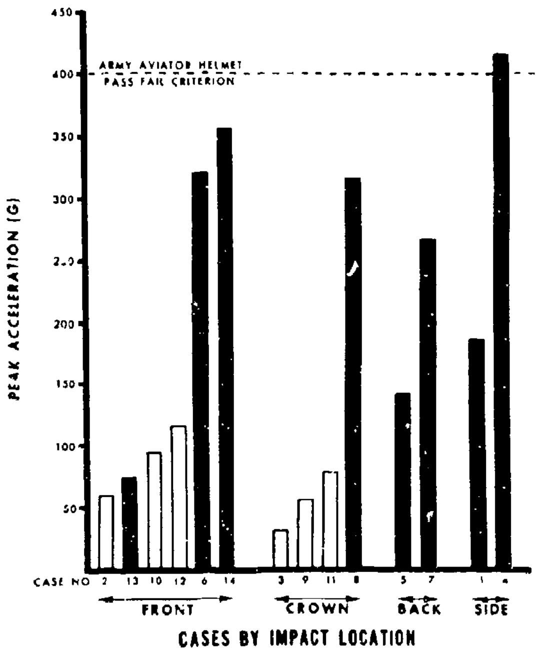


FIGURE 7. Peak acceleration values for the impact best duplicating helmet damage for each of the 14 cases. Solid bars represent cases in which head injury resulted from the impact. Head injury occurred at peak acceleration level well below 400 G.

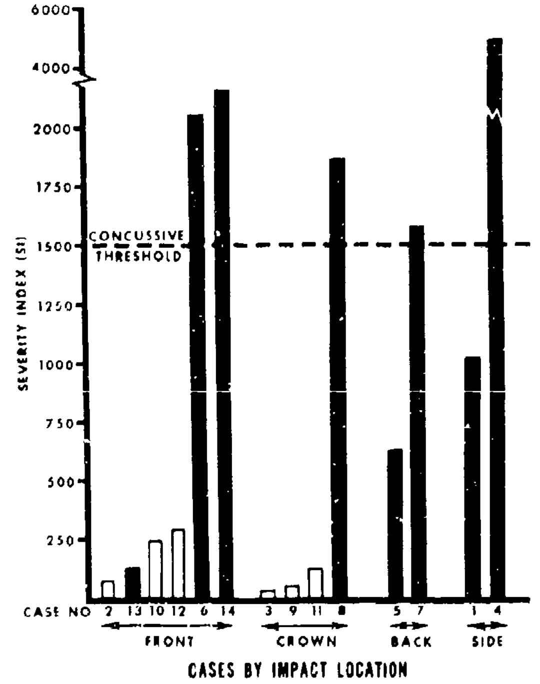


FIGURE 8. Severity Index values for the impact best duplicating helmet damage for each of the 14 cases. Solid bars represent cases in which head injury resulted from the impact. Concussion occurred below the SI value of 1500 used by NOCSAE as the concussive threshold. See Table 1 for a description of head injuries.

TABLE 1

SUMMARY OF IMPACT DAMAGE DUPLICATION DATA FOR 14 HELMETS RETRIEVED FROM US ARMY HELICOPTER ACCIDENTS

Case No.	Impact Location	Shape of Impact Surface	Drop Ht. (m)	Peak Acceleration (G)	Average Acceleration (G)	Pulse Duration (ms)	SI	HIC	Peak Force (N)	Helmet Liner Thickness Before Impact (cm)	Maximum Liner Compression After Impact (%)	Total Liner Area Compressed (cm²)	Impact Energy (J)	Head Injury Description	AIS
2	front	flat	0.38	60	38	7.2	70	63	3140	-	none	none	24	none	0
13	front	concave	0.46	73	38	8.4	123	111	3200	0.983	38	17.0	29	dazed several minutes	1
10	front	flat	0.53	96	55	7.0	239	214	4820	1.054	13	20.6	34	none	0
12	front	flat	0.76	117	40	13.0	285	228	6180	1.021	39	14.6	48	none	0
6	front	flat	1.52	322	139	4.5	2458	2252	17200	1.029	43	21.3	97	basilar skull fracture, unconscious 30 hours	5
14	front	concave	1.91	355	136	6.5	3477	2872	14860	0.983	52	45.6	121	subdural hematoma	5
3	crown	flat	0.15	30	14	16.8	20	17	1000	-	none	none	10	none	0
9	crown	flat	0.46	54	18	17.4	49	37	3520	-	none	none	29	none	0
11	crown	flat	0.46	77	34	10.6	125	109	4200	-	none	none	29	none	0
8	crown	rod 1.27 cm radius	2.29	316	90	9.8	1862	1428	12160	1.118	34	30.5	145	unconscious 2 min, semi-conscious 6 hours, fracture of C_1	2
5	back	bolt head 1.27 cm diameter	1.52	141	54	11.3	629	553	6800	1.029	78	14.7	97	deep scalp laceration, dazed several minutes	2
7	back	flat	1.22	263	81	8.3	1571	1379	11680	0.909	63	26.8	77	unconscious several minutes	2
1	side	hemi-sphere 4.83 cm radius	1.68	184	67	10.9	1019	901	10060	1.080	51	25.0	107	unconscious 100 hours	5
4	side	concave	3.28	415	138	8.1	4849	4432	13360	0.991	14	13.2	208	basilar skull fracture with subarachnoid hemorrhage, fatal	5

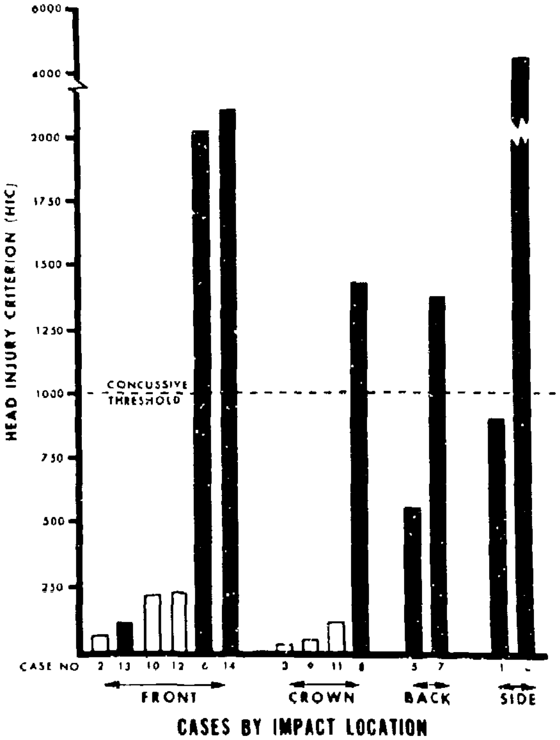


FIGURE 9. Head injury criterion values for the impact best duplicating helmet damage for each of the 14 cases. Solid Bars represent cases in which head injury results from the impact. Concussion occurred below the HIC value of 1000 used by DOT. See Table 1 for a description of head injuries.

The pass-fail criterion currently used by the Army to evaluate the impact performance of prospective aircrew helmets does not appear related to human tolerance limits to head impact. In seven of the eight cases in which head injury did occur, a helmet permitting the peak acceleration experienced by these individual heads would have passed the current Army impact performance standard set at 400 G as shown in Figure 7. It would appear that the pass-fail criterion currently used by the Army selects helmets which, for the most part, prevent death in crash situations but certainly do not prevent concussive head injury. Considering the potentially hostile post-crash environment--such as fire, drowning, and capture--the injury level permitted by the current pass-fail criterion is unacceptable. To be effective in selecting aircrew helmets to prevent concussive head injuries in survivable helicopter crashes, the pass-fail criterion should be set at no higher than 150 G, as can be seen in Figure 7. Even though Snively and Chichester (1961) reported that man can withstand helmeted head impacts exceeding 450 G, he was referring to surviving the initial impact only, not a helicopter post-crash environment. Based on case No. 4, where a fatal head injury resulted from a peak acceleration of 415 G, it can be questioned whether or not even an initial impact of 450 G could be survived with any degree of certainty.

Swearingen (1971) duplicated the impact conditions involving the crash of a military helicopter. He reported that the pilot involved received a frontal head impact and experienced a peak acceleration of 435 G without sustaining any head injury. Even though differences exist between individuals in their tolerance to head impact, it seems highly unlikely that very many individuals exist who could withstand head acceleration of this magnitude without experiencing at least concussion. As shown in Figure 7, the peak acceleration associated with all eight cases involving head injury in this study fell below 435 G. In particular, cases 6 and 14 were frontal impacts in which very severe head injuries resulted (AIS value 5) from peak accelerations of 322 G and 355 G, respectively.

The values of peak transmitted force were recorded for each of the 14 cases in an attempt to validate the value of 5000 lb (22.3 kN) currently specified in British Standard 2495 (1960) as the limit of survivability for helmeted head impacts. As shown in Figure 10, the one case of fatal head injury occurred at a peak transmitted force of 2982 lb (13.3 kN). In addition, severe head injury occurred (AIS value 5)

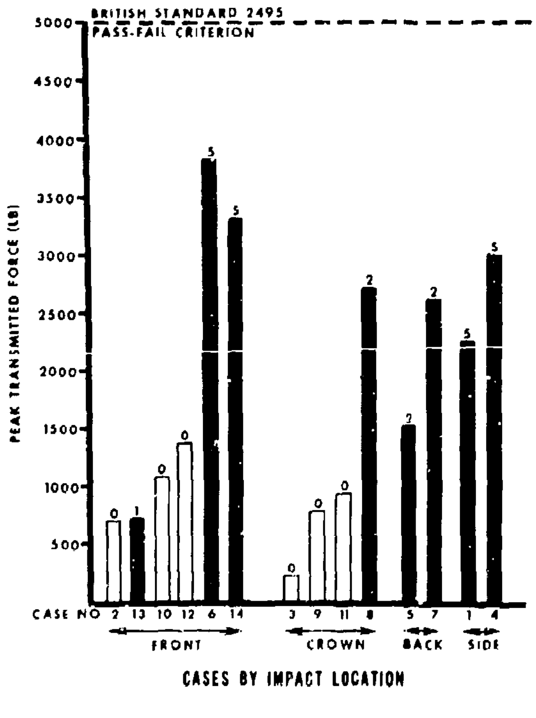


FIGURE 10. Peak transmitted force values for the impact best duplicating helmet damage for each of the 14 cases. Solid bars represent cases in which head injury resulted from the impact. Cases 6, 14, 1, and 4 had an AIS value of 5 with case 4 being fatal.

in cases 6, 14, and 1 at peak transmitted force values of 3839 lb (17.1 kN), 3317 lb (14.8 kN), and 2246 lb (10 kN) respectively. It would appear that a peak transmitted force value of 5000 lb exceeds the limit of survivability.

To what extent the SI value of 1500 or the HIC value of 1000 should be lowered to increase its effectiveness as a predictor of concussion is difficult to establish on the basis of only 14 cases. Continuing this research effort on helmets as they become available should help to define these concussive threshold values.

CONCLUSIONS

To be effective in selecting aircrew helmets to prevent concussive head injuries in survivable helicopter crashes, the current pass-fail criterion of 400 G should be reduced to 150 G. While the SPH-4 aviator helmet adequately protects against penetrating types of head injury, its energy absorbing qualities do not adequately protect against concussive head injuries. The severity of impact surfaces encountered by US Army aircrewmen in survivable helicopter crash situations seldom exceed that of a flat surface. An SI value of 1500 and an HIC value of 1000, currently used as concussive thresnold values by NOCSAE and DOT, respectively, exceed the level at which concussion occurs.

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